computer-assisted theory building

MODELING DYNAMIC SOCIAL SYSTEMS

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Contents

Preface

This book has the immodest goal of reorienting how many social scientists go about building and working with theories. There are three points in my proposals. First, I believe that we would benefit from a shift in substantive focus toward less concern with statics to a more explicit concern with dynamics. Second, I believe that social scientists' theoretical work would be much advanced by the use of powerful and flexible formal languages for expressing theory, as opposed to the current practices of using either "everyday" language or mathematics. Third, I am advocating the use of computer-assisted simulation methods as a useful way for theorists in the social sciences to explore the implications of their newly developed theories of complex dynamic processes.

Examples are often far more convincing than advocacy in the abstract, and this volume is primarily devoted to the development and analysis of formal language models that represent both new and existing social science theories of dynamic processes. There are three stages in the presentation. In the first part of this volume the necessary ideas about "systems" as a way of thinking about dynamic processes are introduced, along with one "semimathematical" language for formalizing theoretical statements about systems. In this section as well, an outline of the strengths, weaknesses, and methods of simulation analysis for theorists is given. In the second part of the book we show how these ways and means can be used to represent and work with large classes of dynamic models that are already in wide use in the social sciences. In the third section we offer some more complex and speculative theoretical statements that illustrate how much further social scientists can go in theorizing dynamics than most currently do.

The approaches and tools presented here are widely used in applied disciplines (engineering, administration, urban planning, etc.), and are not original to the author. These concerns, methods, and approaches, however, have been very unevenly adopted in the social sciences. Some economists will find many of the approaches offered here rather familiar, as both formal theorizing and the use of simulation methodology are widely used in that discipline. The emphases in the current work on dynamics (rather than "equilibrium" analysis) and on use of "friendlier" semimathematical languages should, nonetheless, be of interest. A smaller number of political scientists and still fewer sociologists and psychologists will find the approaches familiar and noncontroversial. That they have not been widely adopted in these disciplines is, in my view, quite unfortunate, for they bridge major gaps between those who study "structures" and those who study "processes" and gaps between those who use "natural" language to present their theories and those who use formal languages (often mathematics or symbolic logic). They allow far more powerful and rigorous ways of "doing theory" than are often practiced. Still fewer practitioners of anthropology and history will find the contents of this volume familiar. But the methods of representing patterns of social dynamics in formal models and understanding their implications by computer-assisted experiments have a great deal to offer. The focus of the methods advocated in this volume on the study of over-time processes is completely sympathetic with the needs and interests of many workers in these disciplines.

Because the approach to building theories advocates a "middle way" between purely verbal models on one hand and mathematical models on the other, practitioners of either approach in any of the social science disciplines may find things here that are of interest and use. Through the development of increasingly complex and nuanced models as we proceed through the chapters, those who fear that the richness and complexity of natural language models will be lost in formalization will see that the current approach does not sacrifice richness for representational rigor. For practitioners of graph theory, differential equations, game theory, Markov models and other forms of mathematical modeling, the payoff is different. The freedom of model form allowable by the use of "semimathematical" languages for stating theories and the use of simulation methods for their analysis allows for the development of more complex and realistic models of forms of social action.

A large number of people have made important contributions to parts or all of this book. The most critical of these contributions has been by my wife Patricia who has not only motivated and supported me while I've worked on the project, but has also served as my main critic, editor, graphic artist, and production assistant. Without this support the book would simply not exist. Debts of this magnitude cannot be adequately acknowledged. The dedication of this volume to her is the best that I can do.

A number of my colleagues have also made direct and immediate contributions to the development of this volume. Randall Collins, who

has been both a teacher and occasional student, contributed much of the work on Marx in Chapter 13, as well as continuing encouragement, and extremely useful critical commentary and suggestions on the manuscript. Jonathan Turner has been of immeasurable assistance in encouraging and supporting the enterprise and by his useful editorial and critical commentary. Another current colleague, David Morgan has contributed to the ideas on stress, coping, and social support in Chapter 12, and to their development into that chapter. To David as well go thanks for support, encouragement, and useful insights and commentary throughout the project. The materials in Chapter 13 on the work of Vilfredo Pareto are the direct outgrowth of earlier work done by Charles Powers, and owe much of whatever value they may have to his contributions to both interpreting and formalizing Pareto's works. Less immediate, but extremely important contributions to the development of this work have been made by two of my former mentors and now colleagues. Jerald Hage first interested me in problems of theory construction, formalization, and dynamics years ago as a graduate assistant. I can only hope that he is not too displeased by the results. J. Rogers Hollingsworth has also been important in the development of this work both through his friendship and through his help in developing and refining many of the ideas on the methods presented. Work that we have done together related to this volume and to other projects have provided a continuing source of stimulation and encouragement. Direct thanks are also due to the staff of the Department of Sociology at the University of California, Riverside for their patience and help, and to large numbers of students who have suffered, willingly and not, through the development and trial runs of many of the elements of this manuscript.

Part I

Social Dynamics

This book is intended to give practicing theorists in the social sciences a new set of tools for creating and analyzing theories about processes of complex social action. The dynamics studied by economists, political scientists, sociologists, anthropologists, psychologists, and historians are composed of multiple simultaneous causal processes, operating along multiple dimensions, and occurring both within and between social actors. Such processes are inherently complicated.

With few exceptions, the task of creating coherent and useful theories about the dynamics of such systems of action has tended to overwhelm us. In efforts to cope, we focus on long-run equilibrium tendencies and comparative statics, rather than on the often more complicated dynamic processes; we progressively simplify problems by assumption until what remains can be dealt with systematically; and, often, we resort to the use of statements at such high levels of generality and abstraction that our theories, however insightful, complete, and consistent, are difficult to verify and offer little guidance in explaining real events.

Effectively creating and analyzing theories about complex processes of social action requires the use of new intellectual tools. At present, theorists concerned with dynamics tend to be divided into two methodological camps (and into numerous factions within each camp). These groups and factions exist in each of the social sciences, with one approach more common in one discipline, and another being the "normal" way of theorizing in another. One group utilizes "everyday" language for constructing theories, including special rules for the definitions of concepts and for making statements about relations among them. Theories are formulated and their properties and implications explored using rules of logic (e.g., axiomatic deduction). Another large group of scholars utilize formal mathematical language tools (e.g., differential equations, Markov processes, etc.) to state theories of dynamic social relations and to analyze and explore their theories.

Everyday language and mathematics are both less than perfect tools for describing and analyzing complex social action. Purely verbal formulations are often insufficiently specific; mathematical formulations tend to be too restrictive. In this volume we will show how the use of specialized formal languages that lie between the everyday and the mathematical can build on the strengths of each and become a powerful tool for stating formal theories of even relatively complex social dynamics. We will also show that computer assisted simulation of dynamic theories provides a "third way" of analyzing and understanding the implications of theories about complex action that is in some ways more powerful than the logical deductive approach associated with "everyday language" formalization and the direct solution approach associated with mathematical formulations.

Our argument proceeds in three main stages, which constitute the major sections of the book. In this first section we will introduce the basic elements of a "systems" approach to creating formal theories of social dynamics, and discuss the use of simulation methods in the theory construction process. In the second section of the book we examine a number of "simple" systems that include many of the major mathematical dynamic models commonly used by social scientists. In the third section we explore some of the applications of semimathematical languages and computer-assisted simulation for dealing with social dynamics that are more complex than most of the mathematical models currently in use, and approach the level of complexity of some everyday language models. These models are extremely rich in the kinds of processes that they can represent while retaining much of the analytic rigor of less complex mathematical models.

The first order of business (and the first chapter) is to get a grasp on the problems of theorizing in the social sciences that this book is intended to address, and to outline our proposed solutions. In this book we stress the importance of theory about dynamic processes as well as about comparative statics, emphasize the need for formalization of such theories using semimathematical language, and advocate a "systems" approach to conceptualizing complex social action. The purpose of the first chapter is to explain these emphases.

The remainder of the first section (i.e., Chapters 2 through 5) explains our approach and acts as a primer on the concepts and language that will be used throughout the volume. In the second chapter the basic elements of systems thinking and formal languages for representing dynamic processes are discussed. In the third and fourth chapters the necessary specifics of one particular semiformal language for continuous state continuous time dynamics (DYNAMO) are explained. In the fifth chapter the notions of systems complexity and the use of simulation methods for working with complex systems are discussed. Taken together, these chapters provide all the tools that the reader will need to understand the models developed in the second and third parts of the volume, and to begin translating their own theories into formal dynamic models.

1

Dynamics, Formal Theory, and the Systems Approach

What social scientists do when they theorize is remarkable in its diversity. They have a variety of goals, ranging from creating time- and space-invariant general laws of social behavior to seeking to uncover and understand the "deep structure" of everyday life. Theorists use a variety of theory-building methods, ranging from deductive reasoning by rules of formal logic to efforts to understand and offer "thick" descriptions of the patterns of meanings and definitions of situations of people in everyday settings. Social scientists are concerned with both large-scale and small-scale human behavioral patterns, are concerned with economic, political, and cultural phenomena, and approach their subjects from a wide range of paradigms.

One of the main goals for all theorizing, regardless of specifics of problem and perspective, is the creation of a mental model of the phenomenon to be understood and/or explained. The models that social scientists build are quite varied in form. Most describe and classify patterns of social action, and identify traits that tend to covary. Fewer take as their problem the processes that create these patterns of co-occurrence. Most social scientist's models are stated in everyday language, and are rich in their ability to evoke analogies and create insights. Fewer are stated with the precision and rigor of formal languages. Most social scientist's models deal with particular phenomena, or narrow classes of phenomena. That is, they are theories of the "middle range." Fewer of our models are useful for understanding the similarities and differences across wide ranges of patterns of social behavior.

We believe that social scientists give too little attention to the tasks of building models useful for understanding social dynamics, relative to the emphasis on comparative statics. We also believe that too little use is being made of the power of formal languages in stating and analyzing theories, relative to the emphasis on narration and description. And we believe that too little attention is given to building theories of broad classes of social behaviors, relative to the emphasis on theories of this, that, and the other specific phenomena.

In this volume we are going to advocate, by discussion and example, some different emphases for theory builders in the social sciences. Our emphasis is on the creation of theoretical models for the analysis of social dynamics, rather than statics. Our emphasis is on the use of formal languages and computer-assisted simulation as a means of theoretical analysis, rather than everyday language. And, our emphasis is on theoretical models as realizations of the more general systems principles, rather than as unique to each phenomenon.

The first task, to which we will devote the remainder of this chapter, is to explain the returns that can be had from an investment of effort in constructing theoretical models about dynamics, using formal languages, and approaching the task of theory building from a systems perspective.

From Comparative Statics to Dynamics

The most common kinds of theoretical statements in the social sciences have the following form: The greater the X, the greater the Y.[1] This type of theoretical statement is an assertion about patterns of hypothesized covariation among the properties described by the concepts. As such, it is a statement of comparative statics.

Theories of comparative statics are tremendously important in the social sciences. They serve to map the territory by providing definitions and classifications. Mapping the patterns of covariation among the parts of a phenomenon helps us to understand that certain forms of behavior or action are unlikely to occur and that other patterns are more likely to occur. Assertions that properties tend to covary and to co-occur imply that causal mechanisms are at work to produce this end. Comparative statics then lead in the direction of a search for the causes of patterns of co-occurrence, and often provide considerable insight into causal mechanisms.

Theories of social dynamics differ from theories of statics in that they focus on the process of change as the thing to be explained rather than the structures themselves. The difference can be subtle. Compare the statements "the greater the centralization, the greater the formalization" and "an increase in centralization produces an increase in formalization." The former statement clearly focuses attention on the assertion that centralization and formalization tend to co-occur, but does not give us any guidance as to why this is the case; the latter statement clearly asserts that a change in centralization produces a change in formalization. Here, as in theories of dynamics generally, attention is focused on the causal mechanism rather than the covariation itself.

The building of theories of statics and of dynamics are closely related and mutually dependent activities. While the focus of theories of comparative statics is not on the processes that produce and reproduce the structures, such theories almost always (but often implicitly) are accompanied by a mental model of where structures come from and how they change. Indeed, one of the key ways in which types of structures are distinguished from one another is through differences between the processes that produce and reproduce them. Similarly, theories that focus on "process" or social dynamics must have (at least implicitly) models of structure embedded in them. There is little meaning in assertions about change in general (though we can make assertions about processes of change that we believe have wide application), without referring to the structures that are connected by such processes.

Greater emphasis has been given to statics than to dynamics in most social science theorizing. And, while comparative static analysis is a necessary and important task, too much emphasis can deflect attention from other important theory-building tasks.

To the extent that social scientist's theoretical activities seek to build explanations of phenomena, rather than descriptions, they must focus on causal processes that occur over time. In the life sciences we see elaborate and effective taxonomical systems for mapping and describing organisms. These systems are remarkable intellectual achievements, but are useful only because they are closely tied to causal theories about the origin, selection, and retention of species differences. That is, the static taxonomy is closely connected to the theories of selection dynamics.[2] Similarly, the distinction between the "extended family" and the "nuclear family" is useful primarily because it is tied to (and helps us to build theories about) the causes and consequences of patterns of variation in interpersonal relations. The distinction between a "market" and a "hierarchy" similarly is useful primarily in the context of explanations about the processes that cause the emergence of these forms, or the consequences of these forms of coordination. Static comparisons in the social sciences, then, are usually no less grounded in dynamic theories than the physical or life sciences are—though social scientist's dynamic theories are often poorly developed, leading to poorly developed and competing static models.

Dynamics, then, should be a top priority in social science theorizing because of the role that they play in motivating comparative and static analyses. But dynamics can (and should) be a central object of theorist's concern in their own right. It is often the case that the phenomenon that needs explanation is the rate of change in some pattern of social action, rather than variability in the pattern itself. Some examples will make the point. A psychologist may be interested in the rate of cognitive development (i.e., change in the level of the construct with respect to time) as it is affected by life experiences. A social psychologist might focus attention on changes in the rates of communication or of affective support among members of a social network over time. An anthropologist may wish to explain the rate of diffusion of a belief pattern within and among the tribal units in an area. Sociologists may wish to account for changes in the level of income and occupational prestige of individuals over their life-cycles. The interest of political scientists may be drawn to the processes that generate changes in the level of support for parties or candidates over time. Economists focus attention on rates of growth and changes in prices. In each of these cases (and clearly many more could be cited), the central theoretical problem is one of understanding change per se, rather than patterns of covariation or the equilibrium realization of the systems.

Where the goal of the theory building enterprise is to provide mental models for understanding change, theorizing that deals explicitly with dynamic processes may be more appropriate than theorizing in the static mode. Building theories about dynamic processes may also have some practical advantages in the continuous movement back and forth between theory formalization and observation. In making observations about social action, either during the process of constructing theories or of verifying them, we are often able to observe the dynamic behavior of systems, but rarely able to observe systems in their static or equilibrium states.

In the process of making theoretical generalizations on the basis of observations, we are sometimes in a position to identify causal connectedness among properties, but do not have available cases in which all the causal processes have reached their full realizations. That is, we may not have examples of the "normal," or "stable," or "ideal-typical" ways that the elements fit together. It may also be the case that we wish to create a theory to understand the workings of processes that occur only once (e.g., the rise of the capitalist world economy). In this instance we do not have multiple cases to compare in order to attempt to uncover the nature of the processes that generate variability in outcomes. In either of these circumstances, we can still use our observations to attempt to formulate theoretical statements about variations in the rates of change in properties of the social system. That is, it is possible to create a theory of dynamics, or change with respect to time, even when events are not repeated and do not ever reach an equilibrium condition.[3]

The verification of theories of comparative statics is often difficult because of the requirement of comparing multiple cases and the requirement that the cases be in their final or "equilibrium" conditions. In experiments we are often able to observe multiple comparable examples of fully realized dynamic processes. Most other forms of observation (participant and systematic observation, use of archival and statistical records, questionnaires and surveys, etc.) yield data that are more problematic. The multiple observations (cases) are rarely "equivalent" in important ways, they are not randomly selected into treatment groups, and the effects of independent variables on change in the dependent variable have not necessarily been equally or fully realized across observations. All of these realities about the data arising from observational methods in the social sciences can raise difficulties for using observations to build good static theories. Theories about dynamics, because they imply observation across time, rather than across cases, are less subject to certain of these problems (and are more subject to others). Data on event histories or time series may be easier to come by in the nonexperimental branches of the social sciences than truly comparable cross-sections, and hence may bring observation and theorizing closer together.

The argument for a greater concern with theories of social dynamics and hence for techniques tailored to building them is relatively simple, but, we hope, convincing. Many of the fundamental theoretical questions of social scientists are explicitly questions about rates of change in patterns of social action. For such processes as growth, decline, status transition, modification and elaboration of form, the most powerful and direct way of stating theory is in terms of dynamics. Theories stated in terms of rates of change may also be more useful than those stated in terms of patterns of static covariation in certain cases for more practical reasons. There are many phenomena about that social scientists may wish to theorize that either fail to ever reach equilibrium or else are not repeated. In these cases, theory formulation and/or verification by means of static comparisons are simply not possible, and observations of rates of change in one or more realizations must form the empirical base for theorizing.

Formalization: The Languages of Theory Building

One of the issues about theory-building methods that most deeply divides practitioners is the question of the most useful languages for creating theory. At one extreme, some would argue that theories about social action must be stated in the language of the actors and settings about which the theory is written. Near this extreme position is the view of "historicist," "ethnographic," and "institutionalist" scholars in the various social sciences. These positions all emphasize the virtues of rich, evocative, and "thick" description of phenomena. Practitioners in these traditions have, not surprisingly, strong preferences for the use of "everyday" language in making their theoretical statements. At the opposite extreme, some social scientists argue that theories of social action ought be constructed using the most abstract and general languages possible. Social science historians, social network analysts in sociology and anthropology, mathematical sociologists, and others of their ilk in political science, economics, and the applied social sciences display strong preferences for the use of restrictive formalisms (e.g., statistical and mathematical tools) for making theoretical statements.

At the root of much of the diversity of views about the language appropriate for building theory in the social sciences are important epistemological debates about empiricism and about the possibility of general laws in social and cultural sciences.[4] Our concern with language choice here, however, is far narrower.

There are a variety of different ways of talking about economic, political, and cultural dynamics, and for stating theories about them. In practice, models about dynamic relations are most frequently formulated utilizing either everyday ("natural") language, causal models based on linear structural equations ("statistical") language, or differential equations ("mathematical") language. Each of these languages for describing dynamic relations has certain strengths and limitations, and each tends to create habits of thought affecting the types of theories that we build. In this volume we advocate a language for constructing theories about continuous state dynamics that is a hybrid of natural and mathematical language. Since we will ask the reader to become familiar with the basic vocabulary and syntax of this language, we need to explain why the use of a formal language for building theories of dynamics is desirable. And, we need to suggest why a new language is preferable to the ones that we already know.

Everyday Language

By far the most common language of stating theories about social dynamics is the same one we use in everyday discourse, with some slight tailoring for the purpose (i.e., creating "jargon" to define particular types of things and relations among them). We might, for example, state a theory about a particular form of social dynamics as follows: The more time that actors spend in direct face-to-face interaction, the more they will come to perceive that they share many things in common with one another. As they come to perceive themselves as more similar to one another, they come to form increasing feelings of liking or attraction to one another; as feelings of attraction increase, the actors will strive to prolong the interaction.[5]

This statement is clearly a theory about social dynamics, and a very important one at that. There are actors (individual persons), each is characterized by levels of continuous variables (call them, say, propensity to initiate interaction, degree of perceived similarity to the other, and strength of liking or attraction for the other), and the model specifies causal relations operating over time among the variables. The statement of the theory has a number of appealing features: The terms used have meanings we understand without special effort, the relations are simple and straightforward, and the empirical referents of the statements are easily discerned, thereby making empirical examples readily accessible that are consistent with (or contradictory to) the general statement.

A closer look at the theory, though, reveals some problems. These difficulties are typical consequences of formulating theoretical models in everyday language. First, there is a tendency to overgeneralize when stating theories in this fashion. The formulation of the theory above does not tell us the conditions under which the proposed relationships hold, nor does it specify conditions limiting or modifying the relationships in question. Second, the theory statement fails to enlighten us on a number of points: Are the relationships linear? (That is, does each increase or decrease in perceived similarity generate the same increase or decrease in liking, or are there thresholds?) What are the time-shapes of the relationships? (Does the propensity to interact respond immediately to changes in liking, or are there lags and delays?) Do the relationships run in one direction (Does increased similarity cause increased liking, but not vice versa?) or in both directions? Are similarity, liking, and interaction levels "self-referencing"? (Do changes in the degree of liking depend on the degree of liking that already exists? Does liking increase, decrease, or remain the same in the absence of change in similarity and interaction?)

What these questions really boil down to is this: Theoretical statements in everyday language tend to fail to precisely specify the relations among concepts. Of course, one could ask how precise the theorist is obligated to be. The position taken here is that a statement of a theory must be specific enough to enable us to create a class of models that have important commonalities of dynamic behavior and to be specific enough to eliminate from consideration classes of models that do not produce the same basic patterns of behavior.

The statement of the theory above is not sufficiently specific by this criterion because it allows for "interpretation" at so many points that it is consistent with models that produce a wide variety of fundamentally different dynamic behaviors. In its simplest possible interpretation, the theory is consistent with models that produce accelerating exponential increases or declines in similarity, liking, and interaction over time. However, with very slight modifications that are not ruled out by the theory (as we stated it), increases at different rates for different variables, increases and decreases at decreasing as well as increasing rates, or even (more arguably) some forms of simple cyclical behavior, can be produced by models with legitimate claims to parentage in the theoretical statement. It is our position that such a theoretical statement is not sufficient because of the high degree of indeterminancy in predicted behavior.

The use of everyday language to state theories does not always result in formulations that are insufficiently specified. Much more careful and fuller explication of this theory could remove much of the ambiguity. Everyday language, however, is an awkward tool for such specifications—and particularly for specifying the parts of the theory that are explicitly dynamic.

Everyday languages are evolved to suit certain needs and limitations. Consequently, they tend to have two related characteristics that limit their utility for unambiguous statements of theories: They are (1) richly evocative and (2) highly abbreviated. The terms of everyday language are capable of meaning very different things depending on the contexts in which they appear, and can be understood (in part) as signals or stimuli that set off extremely complex ideas and cognitions when sent between two individuals sharing the same culture. These characteristics are very useful in managing everyday social life, but are not ideal for the statement of theory (though, of course, every statement of theory ultimately has reference to the culture and language of the persons creating and consuming it). The variety of possible meanings of terms and relations among terms in everyday language is very great, and, in many cases allows for the creation of numerous markedly different mental models consistent with the same statement. Everyday language also tends to be highly abbreviated, relying on context and shared culture to "fill in the blanks" so that interaction can continue. In stating theory, such linguistic tendencies result in a failure to specify limits, conditions, forms of relationships among variables, and time-shapes of relationships.

Mathematical Language

At the opposite extreme from everyday language is mathematics. As a language of scientific discourse, mathematics has several advantages over everyday language. All of the information to be conveyed by a statement in mathematical language must be made explicit. Each of the variables in a statement is a pure abstract symbol, and all of the relations among variables are expressed by operators and functions. The vocabulary in the language of mathematics is highly restricted, and each term has a defined and shared meaning. And, importantly, the more complex meanings created by stringing symbols and operations together bear determinate relationships to the parts that compose them. Specialized sublanguages having these desirable characteristics have been evolved that apply well to making statements about continuous state/continuous time dynamics, most notably differential equations and the calculus. With these specialized languages, complex and powerful operations of deduction from systems of statements about dynamic relations can be made.[6]

The use of mathematical language to state social science theories is very common. Such applications are most apparent in theoretical economics and psycho-physics, but are also quite common in almost all of the subdisciplines in the social sciences. The use of differential equations (and their equilibrium form of "structural equations" and their log-linear analogues) are commonplace in political science, sociology, history, and psychology.

There are, however, a number of disadvantages to the use of most existing mathematical languages for stating social science theories, and particularly theories about processes and change. First, it must be admitted, most social scientists are not very well trained in the uses of mathematical language. While mathematics can provide powerful tools for making statements about dynamics, it is of little practical utility if those who wish to make such statements cannot do so coherently and if their statements are unintelligible to those who hear them.

As serious a limitation as this is in practice, there are also two more general reasons for concern about using mathematics as the language of discourse about cultural, political, and economic dynamics. One of these problems is technical, the other stylistic.

The phenomena about which social scientists wish to create theories are quite varied. Some of the social systems are relatively simple, and the theories formalizing the dynamics of them can be correspondingly simple. Other phenomena are exceedingly complex and call for quite complex theories to adequately formalize the laws of their dynamics.

Put very simply, most mathematical languages for stating theories of dynamics are more powerful than we need for simple problems, and not sufficiently powerful for complex ones. Many of the most elegant applications of mathematical language in the social sciences are viewed by some as arid formalisms of trivial problems. They are considered so restricted and oversimple as to be of little general utility. Theories of two-person games and triadic interaction, as well as deductive theory about collective behavior are indeed powerful and explicit, but are often accused of being either good theories about trivial phenomena or being bad theories about nontrivial phenomena. On the other hand, mathematical formulations of complex problems often exceed the capacities of their creators and consumers to understand and explicate them. The introduction of conditional relationships, nonlinear relationships, and complex patterns of coupling among even small numbers of variables can rapidly exceed our capacity to solve such systems, or to comprehend the meaning of the solution if one is found.

In addition to these "technical" limitations on the utility of formal mathematics, there are "stylistic" problems. It is sometimes argued that "natural" or everyday language is the appropriate language for studying cultural phenomena, as in the the humanities. In contrast, mathematics is the language of sciences dealing with material aspects of the world. The problem arises in finding a language of discourse that is fully compatible with both the material and cultural aspects of social action. That is, the language that we use for theory building in the social sciences must not only enable us to talk about "things," but also about "the meaning of things." There is no inherent reason, of course, why everyday language and mathematics cannot be used to deal with both material and cultural phenomena. But neither provides specialized vocabulary or easy syntax for establishing the connections necessary for social science theory.

Semimathematical Languages

Because of the limitations of mathematical languages for stating theories of dynamics—practical, technical, and stylistic—social scientists have created a number of "intermediate" languages that lie between everyday and mathematical languages. These languages seek to retain much of the rigor of definition and deductive power available from mathematical forms, while at the same time they resemble everyday language. One such language, DYNAMO, will be used in this volume.

These "semimathematical" or "intermediate" languages have a number of distinct advantages for social science theory building. On the one hand, they have highly restrictive (but still quite powerful) vocabularies and syntax. As such, they remove ambiguity from statements about the elements of the theory and require complete specification of the exact forms and limits of the relations among the elements. Theoretical models stated in formal languages may be foolish, internally inconsistent, and bear no relation to events in the real world. They cannot, however, be ambiguous and open to various interpretations. The semimathematical languages that have been explicitly formulated for the purposes of stating continuous state dynamic models of social behavior—such as DYNAMO—have rules of syntax that require the theorist to formulate theories in particular ways. These strict rules of definition and syntax, far from restricting the range of possible theories, actually aid the theorist by requiring that certain questions be answered (and hence the alternatives considered) at each stage in formalization of the theory.

As a direct result of the more restrictive vocabulary and grammar of the languages, theories using semimathematical languages tend to be far more tightly structured and explicit than natural language theories. Yet, the most common "semimathematical" languages generally have a more flexible structure than "pure" mathematical ones. For many of the problems about which social scientists want to theorize, this is an advantage, although there is often a substantial price in deductive power to be paid for this greater flexibility of expression of the semimathematical languages.

To propose that we use specialized formal languages for building theories about social dynamics is somewhat radical. Not all will agree that everyday or natural languages are insufficient to specify dynamic relations. Others will not agree with the proposition that "pure" mathematics cannot capture the richness of those phenomena about which we wish to theorize.

The plausibility of these conclusions resides in their illustration. And so, in the remainder of this volume we will develop a series of models of progressively more complex social dynamics within the grammar and syntax of a "semimathematical" language (DYNAMO) that is closely tied to the "general systems" and "systems dynamics" traditions of theorizing about social action. This language is an attempt to bridge mathematics (systems of simultaneous linear and nonlinear difference and differential equations) and theorizing about economic, political, and cultural dynamics from a "systems theory" perspective.

All languages, be they "everyday" or highly formal and specialized, reflect particular ways of seeing the world. The theories and models, and the approaches to theorizing and modeling in the remainder of this volume, are "cultural artifacts" of a particular way of viewing the world: the "systems" perspective.

"Systems" Approaches to Dynamics

In the broadest sense of the term, a "system" is nothing more than an ordering or relating of a set of parts into a whole. A "system" is composed of both the "things" ("elements" or "parts") and the relations among them. Theories are one example of systems in that they consist of parts (concepts) that are ordered by relations (propositions, equations, or other connecting statements) into a larger whole. The things about which theorists theorize can also be seen as "systems" in this broad sense: The mental organization, knowledges and cognitive structures of social actors, patterns of social relations, and basic social forms like community, class, nation, and world "system" are all "systems" of differing compositions and complexity.

In this volume we will be using the vocabulary of "systems" (in this broad sense of "things" and "relations among things") and insights borrowed from the methods of "systems analysis." "Systems analysis" is most commonly thought of as a method for understanding and working with electromechanical devices (such as computers) or highly rationalized human intellectual creations (such as computer programs or the patterns of social relations in formal organizations). As a logical approach to constructing and analyzing theories, however, "systems" concepts and language can be applied to any pattern of relations, and need not be restricted to the study of mechanical or "rational" systems.

The methods of theory building applied by systems analysis are really no different from those routinely taught in courses in theory construction. The first step is to "define the boundaries of the system" to be theorized about. That is, we first must decide on the limits of the phenomenon to be described and provide its definition. The second step is to "define the elements of the state space, and partition the state space into subsystems." That is, we must identify the variables that describe the phenomenon and group them into subsets that make sense for our purposes. Third, we "describe the connectivity of the state space elements, and the forms of relations among the states of the system." That is, we identify which variables are direct causes of change in which others, and describe the limits and functional forms of these causal relations. Finally, we "define the dynamic aspects of the relations among state space elements." That is, we describe how fast each of the causal connections operates, and the "time shape" of the relations among the variables.

The reason that we burden the reader with some new vocabulary (i.e., systems, subsystems, connectivity, state spaces, etc.) to describe already familiar aspects of the theory-building task is that the use of these systems analysis concepts help us to think more abstractly about what we do when we build theories. Particularly, they are very helpful in leading us to see our theories as systems that share properties with other systems of similar structure but different substantive content.

Perhaps the chief virtue of using the concepts of systems analysis to describe the tasks of theory building is that the usage points out the similarities in the enterprises of members of different disciplines, of "micro" and "macro" theorists, and of practitioners from differing paradigmatic perspectives. Certainly social scientists have very different concerns and approaches: A Marxian political economist seeking to theorize about capital flows among nation states in the world system would seem to have little in common with a psychophysical psychologist studying the structure of individual memory. But if we think about the tasks of these practitioners as the building of theoretical systems, their activities are not really so different. In both cases the analysts could be said to be concerned with building theories that describe dynamics: rates of capital flows and rate of information flows. Both problems involve quite large state spaces: the national economies of states in the world system and memory locations in a network or schema. Both problems are systems of relatively high "connectivity": Most nations trade with most other nations, and most elements of memory schemas are quite directly accessible to most others.

This is not an idle exercise in semantics to point out the similarity between these two quite different social science enterprises when seen from the "systems" perspective. That the two problems are so similar suggests that very similar methods can be used for building and analyzing theories about the dynamics of capital flows and the dynamics of memory and recall. These methods, of course, are the subject of the remainder of this volume. The similarity of the two problems also suggests that theorists working in very different substantive areas can obtain guidance and insights about their own problems of theory building by comparing the structure of their own theorizing as a system to other theories as systems, even where the substantive content may be very different. The use of systems concepts, then, can aid in improving communication across and within social science disciplines.

Theoretical activity in most of the social sciences is divided by paradigmatic emphases, as well as by substantive specialization. The

Marxian political economist in our example above differs from the cognitive psychologist not only in the aspect of human behavior that he or she seeks to explain, but also in a series of assumptions about the nature of the important kinds of variables to consider and the ways in which these variables are connected.

Systems thinking and systems analysis are likely to be associated in the minds of many social scientists with a particular set of theoretical problems (i.e., the maintenance of order), particular kinds of dynamics (i.e., equilibrium-seeking negative feedback), and particular policy positions (i.e., "conservative," or possibly "liberal," but rarely "radical"). And indeed, there is a strong historical connection between the use of "systems" language and preferences in theoretical activity in most of the social sciences. But the connection is not a necessary one. Systems thinking is equally consistent with the analysis of contradiction, disorder, and change, as it is with the analysis of harmony, order, and stability.

A large part of the theoretical activity in most of the social sciences (especially anthropology, sociology, history, political science, and economics) can be classified as arising from one of three major traditions: structural-functionalism, conflict analysis, or Marxism.[7] Structural-functional analysis has historically been most closely connected with the use of systems thinking because of the use of systems concepts by theorists in this tradition, and the emphasis of such work on the dynamic feedback mechanisms by which actors and environments are "adjusted" to one another. Conflict analysis has largely avoided the use of systems conceptualization (perhaps because of its association with structural-functionalism), but is quite consistent with systems thinking. Conflict analysis highlights the processes of change in patterns of social relations arising out of the interactions of actors with differing goals and resources. While conflict theorists tend to emphasize disorder and change rather than stability and order, their ideas are completely consistent with systems thinking: Dynamic, goal-oriented interactions among multiple actors are easily conceptualized as systems and can productively be analyzed as such. The historical antipathy between systems theorists and Marxists in most social science disciplines is most peculiar, for Marxist approaches to theorizing are more "systems" oriented than the thinking of most other schools. Marxist analysis emphasizes the inherent tendencies of most systems of social relations to develop strains (dialectical contradictions) that result in their destruction and replacement with new systems. The processes by which systems destroy themselves are just as easy to analyze by systems methods as are the processes that cause systems to maintain or elaborate their structures.

What social scientists do when they theorize is remarkable in its diversity of substance and approach. The concepts of systems theory and the methods of systems analysis provide some useful bridges across disciplines and perspectives and hence are very useful for discussing the building of formal theories of dynamics. Systems terminology helps the theorist to "take a step back" from the substantive issues of the phenomenon they are theorizing and to see the theory itself as a type of system. Once this mental leap has been made, very useful insights can be obtained by applying general principles of systems dynamics to the theorizing of particular phenomena and by borrowing ideas from contexts that are substantively quite different but structurally quite similar to the theorist's concerns. Systems terminology, then, serves as a useful device for describing and organizing the theory building process and for increasing communication across the social science disciplines.

System Complexity, Systems Dynamics, and the Organization of the Book

Our advocacy of the utility of "systems" concepts and "systems analysis" methods for building and analyzing theories of social dynamics should not be taken as an advocacy of "general systems theory." General systems theory is a body of theory about abstract systems—in the broad sense of the term that we are using here. It is an attempt to state general laws about the statics and dynamics of "wholes" composed of "parts" and "relations among" those parts. In its most extreme form, advocacy of the general systems paradigm suggests the possibility of building a "unified" science consisting of general laws that govern the behavior of all phenomena—from systems of subatomic particles to the world ecological-social system. Within the social sciences similar proposals have been made, suggesting that the theories of economists, political scientists, anthropologists, sociologists, psychologists, and others (e.g., management, education, social work, and other "applied social sciences") can be integrated into a single "social systems" framework.[8]

The claim of general systems theory to be able to integrate social science theorizing has been attractive in the abstract (as, of course, are the similar claims of Marxism, structural-functionalism and other "paradigms"), but have not realized in practice. Despite this, many of the central ideas of "general systems" theory do provide useful ways of thinking about problems in each of the social sciences; these same ideas provide powerful tools for seeing similarities (and differences) in the theoretical approaches to problems of dynamics across the social sciences.

We have organized the work in this volume according to one of the central concepts of systems theory in an order of increasing "complexity" of the kinds of theoretical systems discussed. In the first part (Chapters 2 to 5) we will be concerned with learning the vocabulary and syntax of "systems" approaches to problems of dynamics, with learning the basics of a semimathematical language for formalizing dynamic models (DYNAMO), and with strategies for research on dynamic theories utilizing computer simulation. Once we have these tools in hand, we turn to a progression of increasingly complex theoretical models.

Many very important theories about dynamics in each of the social science disciplines are very simple systems. That is, they are composed of small numbers of parts (variables), and relatively simple relations among these parts (usually expressed as sets of propositions or equations). An economist may wish to formalize a system that describes the rate of change in the level of economic production as a function of changes in the supplies of the factors of production; an anthropologist might wish to describe the growth and decline of the population of a village as a function of changing natural and human environmental constraints; a psychologist may theorize about change over the life cycle in individual's "intelligence" or "cognitive development"; a sociologist may wish to describe the rates of fertility in a cohort over time. These "systems" (and, of course, many others) have very similar formal structures qua systems, and may well display similar dynamic behavior. We will examine the structure and dynamic behavior of such "simple" systems in the abstract (Chapter 6), and by example (Chapter 7).

Many additional phenomena from the various social science disciplines can be usefully thought of as slightly more complicated systems composed of several variables connected into "chains." The flows of money in the economy, the patterns of sending and receiving messages in social networks, the movements of individuals through stages of the life cycle, and many other similar problems in all of the social science disciplines have very similar structures and dynamics qua theoretical systems of this type. Some of the varieties of systems representable as simple "chains" are discussed in the abstract (Chapter 8), and by way of several examples (Chapter 9).

Part II (Chapters 6 to 9) provides all of the tools necessary for building and understanding truly complex theories of social dynamics. In the last portion of the volume (Chapters 10 to 13) we will develop some more complicated theories by linking the simpler systems examined in the second section together, and examine their structures and dynamics. The models in this section are developed as solutions to particular theoretical problems (arms races, stress-coping-social support dynamics, and macropolitical-economic dynamics). These models, however, are also generally useful as they illustrate how complex systems are built up out of the coupling together of simple ones—a lesson applicable to the development of all complicated dynamic systems.

One need not accept the claims of general systems theory or of unified social science to utilize the methods of theory building and theoretical research that we advocate in this volume. Implicit in our organization of the materials, however, is the idea that what social scientist do when they theorize about dynamics involves essentially the same set of activities and conceptions (in a formal sense) across all of the social sciences. Without accepting the claims of general systems theory, we do accept the utility of viewing political, economic, and cultural dynamics as dynamic systems. Going one step further, we also implicitly accept the utility of thinking about the theories themselves as systems that can be understood as abstract models and applied across the varied substantive areas of the social sciences.

The particulars of the diagraming conventions and computer language (DYNAMO) that we will use in this volume are derived from one particular school of applied systems analysis—the "systems dynamics" approach of Jay W. Forrester, his students, and colleagues.[9] The approach of "systems dynamics" to constructing formal models of social dynamics is peculiar in some ways, but uniquely well suited to the ways that social scientists go about dealing with thinking about dynamics. As with the use of concepts from "general systems" theory to organize the discussion, however, one need not accept the particulars of "systems dynamics" in order to benefit from the use of the language and tools of this approach. What is of tremendous utility for social scientists about the use of the language and concepts of "systems dynamics" is the structure, rigor, and clarity that comes from thinking about theoretical problems in social dynamics using a semiformal language well suited to our needs.

Conclusions

There are three major arguments in this chapter. First, we suggest that it is useful to distinguish between theorizing about statics and the dynamics of economic, political, and cultural phenomena. A very large portion of social science theory is concerned with static comparisons or with the properties of systems in their ideal-typical or equilibrium states. There is nothing wrong with this. But many theories are directly concerned with process and change rather than structure and stability.

And even theories of comparative statics must have some implicit basis in dynamics. Many of the intellectual tools that we have developed for the analysis of comparative statics are rather blunt instruments for analyzing and formulating theories about change. There is a need ,then, for more theorizing that is explicitly concerned with dynamics and uses tools best suited to dynamic analysis.

Our second argument is that "formal" specialized languages are desirable for creating and analyzing theory in general and theories of dynamics in particular. Everyday language tools for building dynamic theories tend to be too evocative and flexible; mathematical formulations of theory tend to be too restrictive and inflexible. In place of these more common tools, we advocate the use of specialized "semimathematical" languages specifically designed to describe complex mathematical processes (simultaneous linear and nonlinear difference and differential equations) in language that resembles—but imposes restrictions on—everyday language.

Third, we have suggested that many of the concepts of "systems" theory and the language and general conceptual approach of "systems analysis" provides a common ground on which theorists of various stripes can formulate and discuss theories of social dynamics. Without accepting the "general systems theory" world view, or the specifics of the "systems dynamics" tradition within this perspective, we will use these ideas as organizing principles for this volume. As we hope to demonstrate, there is a great deal to be gained from applying systems thinking to the problem of systematic theory building across all of the social sciences.

Notes

1. Such propositions can be made much more elaborate by including mulitple Xs and Ys, by describing the relationship in detail, and by adding limits propositions, all without modifying the nature of the statement as one of static covariation.

2. For an excellent discussion of principles of classification and their connection to causal theories in the life and social sciences, see McKelvey, 1982.

3. There is a considerable epistemological debate, particularly in historical analysis, about whether nonreplicable observations can be used as the observational basis for the formation of covering laws. Obviously, it is the position of the author that observations over time from a single realization are just as valid a basis for generalization as are observations across multiple cases.

4. Epistemological debates surrounding the role of language in explanation and the possiblities of the application of scientific method to cultural phenomena are extremely interesting and important, but go beyond the scope of this volume, which largely presupposes a positivist approach.

5. This particular formulation can be traced to Homans (1961), but is by no means a fair representation of his work.

6. For some interesting discussions of the strengths and weaknesses of mathematical applications in social science theory, see particularly Abelson, 1967, Arrow (1956), Ando et al. (1963), Berger et al. (1962), Hamblin (1971), Kemeny and Snell (1962), Kruskal (1970), Land (1971), Lave and March (1975), Lazarsfeld (1954), and Rapoport (1959).

7. There are, of course, any number of ways of classifying and characterizing paradigmatic approaches in the social sciences. The current classification is used only for purposes of illustrating the general applicability of systems thinking, and makes no claim to be a particularly useful way of talking about the diversity of social science approaches.

8. For broad overviews of "general systems theory" and its applications to "unified science" and "unified social science," see particularly Berrien (1968), von Bertalanffy (1968), Klir (1971), and Kuhn (1963, 1975).

9. A more complete description of the "systems dynamics" perspective and major works in the tradition are presented in the next chapter.